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Physical Techniques for Controlling Birds to Reduce Aircraft Strike Hazards

effects of laser light on bird behavior and physiology

Ohio State University

prepared for

Air Force Weapons Laboratory

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PHYSICAL TECHNIQUES FOR CONTROLLING BIRDS TO REDUCE AIRCRAFT STRIKE HAZARDS

(Effects of Laser Light on Bird Behavior and Physiology)

Sheldon I. Lustick

Ohio State University

TECHNICAL REPORT NO. AFWL-TR-72-159

December 1972

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base
New Mexico

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Three species of birds (starling, Sturnus vulgarus; mallard duck, Anas Platyrhynchs; and herring gulls, Larus argentatus) were used to determine if high-intensity laser light could decrease the bird-strike hazard to aircraft. The effects of both continuous and pulsing light on bird behavior and physiology were determined. The responses of the birds were monitored both visually and electronically. The birds were exposed to both a low-intensity strobe light pulsing at frequencies of from 100 to 1000 per minute and an argon laser capable of emitting either pulsed or continuous light of different wavelengths (454 to 515.5 nm) at intensities of 20 mW to 4 W. The intensity of laser light striking the bird could be varied further by changing the diameter of the laser beam. It was found that a concentrated laser beam of 0.2 cm in diameter at a power above 0.5 W would cause an avoidance response in all the species tested and thus could be considered nonspecies specific. It is also the only light source to which the birds did not habituate. Though the initial response to pulsing laser light of lower intensity (beam expanded from 2 to 14 in.) was increased excitability (increased perch hopping and heart rate) the gulls and starlings soon habituated. The ducks were more sensitive than gull or starling to the expanded laser beam having an elevated heart rate and avoiding the laser beam expanded to 6 inches in diameter at least 50 percent of the time. All species tested showed a group avoidance response and could be denied a portion of the test encloser when exposed to the concentrated laser beam. Also discussed are the feasibility of using a laser system, the problems of using a laser system, and further research needed before implementing a laser system for controlling birds.

14 KEY WORDS	LINK A		LINK B		LINK C	
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FOREWORD

This report was prepared by Ohio State University, Columbus, Ohio, under Contract F29601-71-C-0122. The research was performed under Program Element 63723F, Project 683M3E06.

Inclusive dates of research were June 1971 through September 1972. The report was submitted 1 November 1972 by the Air Force Weapons Laboratory Project Officer, Dr. Jelle de Boer (DEE-E).

This technical report has been reviewed and is approved.

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SECTION I

INTRODUCTION

As man continues to develop the earth, he creates microhabitats which in turn create potential pest situations involving birds. In such new habitats as orchards, cities, and airfields, some species of birds congregate in large numbers, pest situations develop, and there is ultimately a need for some type of control. With the need for control established, one still must determine the control method that will give the best results. Therefore, the following study was conducted to determine if a laser system of bird control could be employed to decrease the bird-strike hazard without any adverse effect to the birds or the environment.

Regulatory methods are of two basic types: the direct methods of scaring, trapping, shooting, poisoning, and inhibiting reproduction, and the indirect methods of altering, shielding or removing a particular environment. In order to use the direct approach the operator must understand the organisms anatomy, physiology and behavior, and to use the indirect approach requires a knowledge of the organisms environment, including food, cover and competing and noncompeting organisms.

For a control program to be sound ecologically it should have specificity. That is, the control program affects only those individuals within the species that are in the pest situation (i.e., on the airfield). Besser[1] has stated that no one pest control technique can be considered a solution for all pest situations. In fact, many control techniques may be needed, with little assurance that they will be effective the following season. Bliese[2] found in four years of trying to control blackbirds that the efforts to control birds in one year had no effect on the blackbird response the following year.

The number of variables affecting a control method is large; for example, weather conditions and age of the birds. Siebe[3] indicated that in summer juvenile starlings were repelled by frightening devices and biosonics, whereas in the fall and winter these same devices were not effective at feed lots where large numbers of adult birds were concentrated indicating that either age or weather conditions affect the bird response to these controlling devices.

At first, control methods relied on fright techniques, followed by lethal techniques, and more recently on the preventive technique. Of course the perfect control would be one which would keep the birds out of the pest situation without destroying the birds or the environment. Up until now we have been considering bird control, in general. What about bird control in and around airports?

Both military and commercial equipment and personnel are endangered when aircraft strike birds. In 1965, 839 strikes were recorded by the Air Force; most were below 1000 feet. In 109 of these cases birds were drawn into the engine and 75 engine replacements were necessary, at a cost of four of five million dollars.[4]

Five basic methods for reducing the bird-aircraft strike hazards have been suggested:

1. Reduce the number of birds by killing.
2. Rearrange bird habitat.
3. Make birds avoid planes.
4. Arrange for planes to avoid birds by use of a radar warning system.
5. Fortify the airplane.

Of these methods, the third would be the most desirable, and has been the subject of much research with various devices (acetylene exploders, biosonics, chemical agents, electronic shocking devices) being adapted for use.[5,6,7] Although these devices are helpful, none has been so successful that there has been a lessening in the need for further research into the means of combating the bird-strike hazard. The other methods mentioned, although they would work to some extend, are generally undesirable. With the general public working to preserve the ecology, the killing of birds and the manipulation of habitat create poor public relations and are essentially undesirable methods. To arrange for planes to avoid birds creates air traffic problems, especially with the present large amount of air-traffic near airdromes, while hardening the plane decreases its efficiency, especially a military plane.

What is needed then is a frightening device which is nonspecies specific that will cause the birds to either leave the airfield or avoid a flying aircraft.

Schaefer[8] suggested research into the use of lasers on aircraft, for confusing or burning birds in the direct line of flight. He stated that a medium-powered gas laser in the visible range could be pulsed so as to confuse birds into diving, escaping or performing stunned motions, when used at 1000 yards. He also suggested the use of a higher power infrared laser to burn birds in the immediate line of flight of climbing or level-flying craft.

To truly understand the psychophysiological effects of a control method on an organism, conditions should be constant, preferably in a laboratory without outside interference.

SECTION II

METHODS AND MATERIALS

1. CAPTURE AND MAINTENANCE

a. Starlings

Thirty starlings (Sturnus vulgarus) were captured on The Ohio State University Farm by use of a large walk-in trap. They were then transported to the laboratory and maintained in individual cages (26 x 24 x 23 cm) in a windowless air-conditioned room. The starlings were maintained on a 12-hour photoperiod (0800-2000 hr), while the air temperature in the room varied between 20° and 24°C. The birds were fed *ad libitum* food (Purina turkey pellets) and water.

b. Mallard Ducks

Twenty mallard ducks (Anas platyrhynchs), 10 male and 10 female, were purchased from Whistling Wing in Chicago, Illinois, and shipped air mail to Ohio State University. These birds were placed in cages (43 x 30 x 39 cm) in an air-conditioned room and maintained on a 12-hour photoperiod (0800-2000 hr). The birds were fed *ad libitum*, a mixture of cracked corn and Purina laying mash. *Ad libitum* water was also supplied.

c. Sea Gulls

Nine juvenile sea gulls (Larus argentatus) were captured on Gull Island in Lake Erie in early June and transported to the laboratory at Ohio State University. The birds were maintained in cages (120 x 56 x 62 cm) in a windowless air-conditioned room on a 12-hour photoperiod (0800-2000 hr). The gulls were maintained on a diet of tuna fish and Alpo dog food (chicken) and given *ad libitum* water. The gulls were not used for experimentation until they reached adult size and obtained adult plumage. To minimize the effect of the laboratory on the birds, they were allowed to adjust to laboratory conditions prior to testing.

2. EXPERIMENTAL PROCEDURE

a. Starlings

Phase I consisted of testing the response of individual starlings of both sexes to low-intensity pulsing light. The light source used was a General Radio strobe light with a pulse range from 100 to 25,000 pulses per minute. The birds were tested in a darkened and lightened room, thus simulating night and day situations. The birds were first tested in total darkness and then at pulse rates of 100, 200, 300, and 400 pulses per minute. Next they were tested in continuous room light (with the strobe off) and in continuous room light with the strobe pulsing at 200 pulses per minute. Each test period (light range) lasted from 30 to 45 minutes, thus giving some idea whether habituation took place. The responses of the birds were monitored visually and mechanically. The birds were placed in a cage (28 x 26 x 22 cm) equipped with four microswitch perchs which, in turn, were connected to a 10-channel variable-speed chart drive Esterline Angus event recorder. The recorder gave us a continuous recording of activity as the birds moved from perch to perch.

The next step was to test the effect of high-intensity laser light on the starlings. To do this we used a Spectro-physics Model 165-03 argon laser in conjunction with a Model 265 exciter. This laser was equipped with a prism, allowing us to vary the wavelength between 454.5 and 514.5 nm, and an all-wavelength mirror, allowing us to administer the entire spectrum between 454.5 and 514.5 nm at once. The maximum power capabilities at different wavelengths (with prism) are given in Table I. With the prism replaced by the all-wavelength mirror, the maximum obtainable power was approximately 4 W. The laser is water cooled and required a flow rate of 2.2 gallons per minute with a maximum water temperature of 35°C.

TABLE I

Maximum output power (W) at different wavelengths for the Spectro-physics Model 165-03 argon laser

Wavelength (nm)	Power (mW)
514.5	1400
501.7	250
496.5	400
488	1300
476.5	500
472.7	150
465.8	100
457.9	250
454.5	100
454.5 - 514.5	4000

To either aim or expand the laser beam, it was necessary to design a telescope and beam director to mount in front of the laser. The telescope (19.1 power) was made by mounting an objective lens of 172-mm focal length and an adjustable eyepiece of 9-mm focal length on an optical bench. The beam director, which consisted of an aluminized first surface mirror (8 x 5.5 cm) mounted on a Coherent Optics Model 58 beam director was placed in front of the telescope so that any light passing through the telescope impinged on the mirror and thus could be accurately aimed by manipulating the micrometers of the beam director (Fig. 1). The laser was also connected to a pulse generator; therefore, we could administer either a continuous concentrated laser beam, a continuous expanded laser beam, a pulsing concentrated or pulsing expanded laser beam, all of varying intensities.

Table II lists the intensity in W/cm^2 on the target (bird) as the diameter of the beam is increased from 0.2 cm to 35 cm.

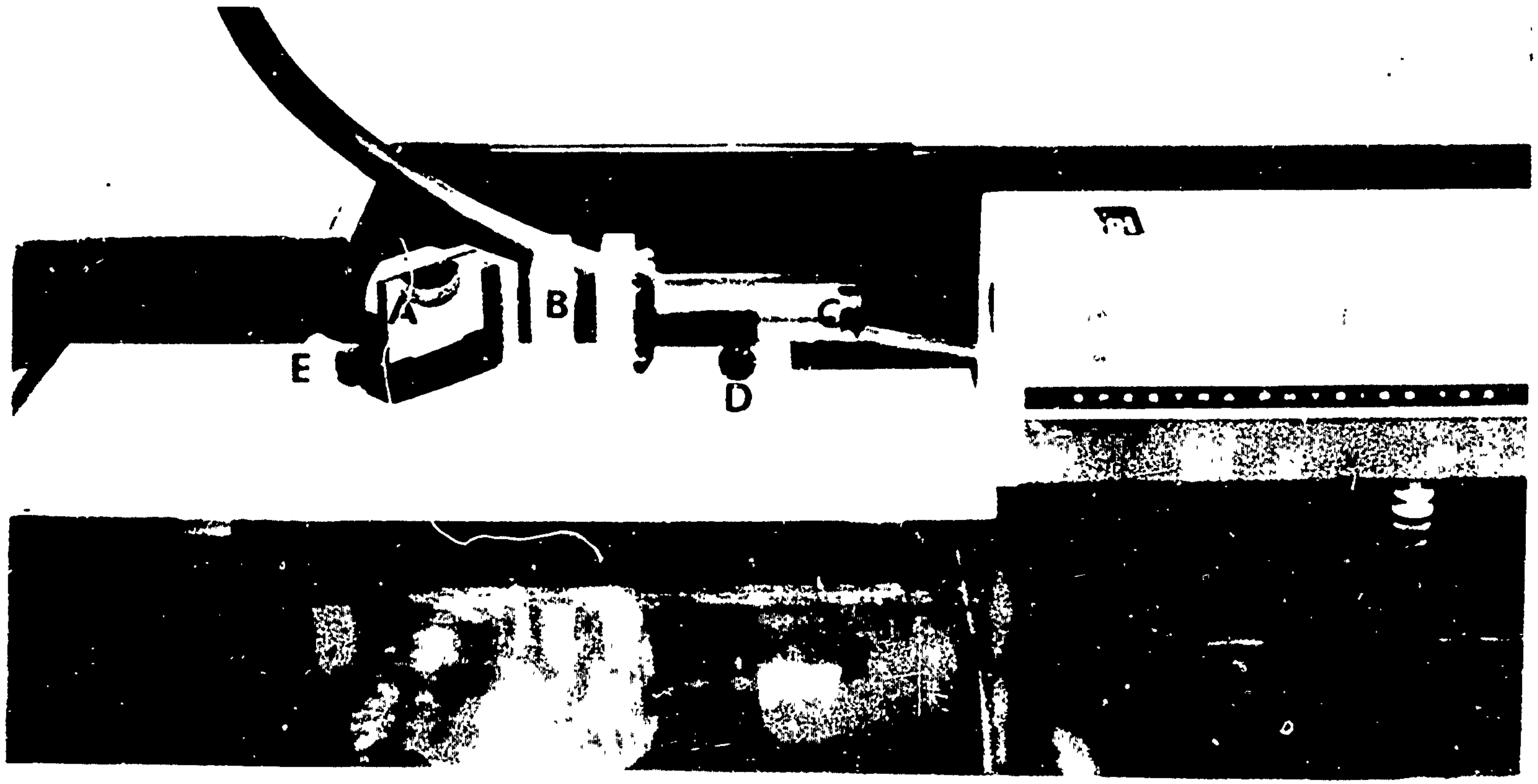
The experimental procedure was similar to that previously described for the strobe light. The birds were first tested by using the concentrated laser beam (continuous and pulsing) at wavelengths of 514.5 and 488 nm and intensities varying between 50 and 1000 mW. The same birds were also tested using the expanded beam (4-5 in.) over the same range of intensities. The experiments were repeated at higher intensities using the all wavelength mirror in place of the prism.

After determining the response of individual birds to high-intensity laser light, we looked at the response of groups of starlings (3 per group) to these same light ranges (all-wavelengths mirror). These experiments were conducted in a much larger enclosure, 60 ft^3. The cage was divided into two equal territories (though the birds could move freely from one territory to the other). We then attempted, through the use of different laser light ranges, to deny the birds one of these territories.

The synergistic effect of a combination starling distress call and high-intensity light on starling activity was tested. The procedure was to pulse the laser at a rate of 200 pulses per minute (4-in. diameter and 2-W intensity) while at the same time playing a taped starling distress call to the bird. The distress call (played on a Uher 4000 tape recorder) was played at approximately two-minute intervals for a duration of 30 seconds. The test period lasted 20 to 30 minutes; the distress call was played from 10 to 15 times during the test period.

b. Mallard Duck

The procedure for testing the effects of low- and high-intensity light on the mallard duck was similar to that described for the starling. In the mallard study the responses were monitored visually, (avoidance response) and electrically, using the heart rate (increased adrenalin) as an indication of excitement. The heart rate was continuously monitored by use of an Narco Bio-Systems telemetry system consisting of a Botelemtry receiver, Model FM-1100-6, and a 18-gram transmitter, Model FM-1100-E2. The telemetry system was used in conjunction with a



A = mirror of beam director
B = objective lens
C = eyepiece lens
D = focusing knob
E = micrometer for aiming beam

Figure 1: Laser and telescope system

TABLE II

Calculated and actual intensity of laser beam on target at different beam diameters (W/cm^2)

Diameter of Beam on Target (cm)	Surface Area (cm^2)	Intensity Setting on Laser (W): 0.05	0.5	1.0	2.0	3.0	3.0
		Intensity on Target (W/cm^2)					
0.2	0.031	1.6 (1.46)	16.0 (14.6)	33.3 (28.0)	66.6 (52.5)	100 (87.0)	116.0
0.5	0.185	0.267 (0.245)	2.67 (2.45)	5.3 (4.7)	10.8 (8.82)	16.8 (14.6)	18.9
1.0	0.785	0.063 (0.058)	0.637 (0.580)	1.27 (1.11)	2.55 (2.07)	3.81 (3.44)	4.45
2.0	3.14	0.016 (0.014)	0.159 (0.140)	0.318 (0.278)	0.638 (0.520)	0.955 (0.860)	1.11
2.5	4.89	0.010 (0.009)	0.101 (0.093)	0.204 (0.178)	0.410 (0.333)	0.615 (0.550)	0.718
5.0	19.62	0.0025 (0.0023)	0.025 (0.023)	0.051 (0.044)	0.102 (0.083)	0.155 (0.138)	0.179
10.0	78.5	0.0006 (0.00058)	0.0063 (0.0058)	0.0127 (0.0111)	0.0255 (0.0207)	0.0380 (0.0344)	0.0445
15.0	176.0	0.0003 (0.00025)	0.0028 (0.0025)	0.0056 (0.0049)	0.0113 (0.0092)	0.0171 (0.0153)	0.0199
35.0	961.4	0.000052 (0.000047)	0.0005 (0.00047)	0.0010 (0.0009)	0.0021 (0.0017)	0.0031 (0.0028)	0.0036

Numbers in parentheses equal laser power on target as determined with a Scientech laser power meter Model 3600.

Packard-Hewlett Model 120-B oscilloscope and a Narco physiograph. This enabled us to continuously view and record the heart rates of the ducks under the various light ranges. An 18-gram transmitter was taped to the duck's back with masking tape. The electrodes which were gold-plated safety pins were pinned just under the skin below the humerus of the wing. The transmitter seemed to have no effect on the behavior of the bird. The enclosure used was the same as that used for groups of starlings. Individual ducks (fitted with transmitter) were placed in the test cage and allowed to adjust for 30 minutes in the dark. They were then exposed to various light ranges from the strobe light in both a darkened and lightened room. The light ranges consisted of total darkness, darkroom plus strobe pulsing at 100, 200, 300, 400, and 1000 pulses per minute. The experimental procedure in Table III was carried out under simulated day and night conditions with the all wavelength mirror. Under daylight conditions, the time it took the duck to avoid the laser beam was used in place of heart rate as an indication of excitement. The same laser light range was tested on groups of three mallards.

c. Gulls

The experimental procedure for determining the effects of low- and high-intensity light on gull behavior was similar to that used for the ducks except that the diameter of the laser beam was changed (concentrated, 1 cm, 2 cm, 2, 4, and 6 in.). All tests were conducted at an ambient temperature of between 22° and 25°C.

TABLE III

Laser light ranges used to test the Mallard duck

Beam Diameter (on target) (cm)	Power Setting on the Laser (W)					
	0.05	0.5	1.0	2.0	3.0	2.0 Pulsing (144/min)
0.2 - 0.5	x	x	x	x	x	x
5	x	x	x	x	x	x
10	x	x	x	x	x	x
15	x	x	x	x	x	x
35	x	x	x	x	x	x

x = light range tested

SECTION III

RESULTS

1. STARLINGS

a. Low-Intensity Strobe Light

The response (perch hops) of individual starlings to pulsating light from the strobe is shown in Fig. 2. As one would expect from a diurnal bird, there is very little movement by the bird kept in total darkness, (0.113 perch hops/min). There is also very little activity in birds kept in a dark room with the strobe light pulsing at either 100 or 200 pulses per minute (0.514 and 1.55 perch hops/min, respectively). In fact, there is no significant ($P > .05$) difference between starlings in total darkness and at 100 to 200 pulses per minute. However, at these pulse rates (100-200 pulses/min) the starlings undergo displacement behavior (rotating of the head, pecking at cage, and staring at the light) which is an indication that they are nervous. At 300 pulses per minute there is a significant increase ($P < .01$) in the amount of perch hopping over that of the lower pulse rates; birds now moving at a mean rate of 18.6 hops per minute. As the pulse rate was increased to 400 per minute, there was again a significant increase in activity.

We tried next the effect of continuous room light (strobe off). As can be seen from Fig. 2 there was a significant ($P < 0.05$) increase in perch hop activity over that of birds in a dark room with the strobe pulsing at 400 per minute.

The next question to arise is, if the strobe at low pulse rates (100-200 pulse/min) can cause displacement behavior, indicating excitability in the bird, can the strobe (200 pulses/min) plus continuous room lights (simulating daytime conditions) elicit greater activity than continuous light? From Fig. 2 it can be seen that strobe light (200 pulses/min) plus continuous room light increased activity (perch hopping) significantly ($P < 0.1$) over that of continuous light. There seemed to be little habituation to pulsing light after one test. For example, on the light range consisting of continuous light plus 200 pulses per minute, the mean activity at the start and 15 minutes later was 60 and 55 perch hops per minute, respectively.

b. Starling Exposed to Laser Light

The effect of the unexpanded continuous laser beam at wavelengths of 514 and 488 nm at intensities ranging from 20 mW to 1 W was tested on starling behavior. At intensities between 0.5 and 1 W and wavelengths of 514 and 488 nm, the laser beam is capable of igniting the bird's body feathers (smoke rises from bird). Oddly enough this

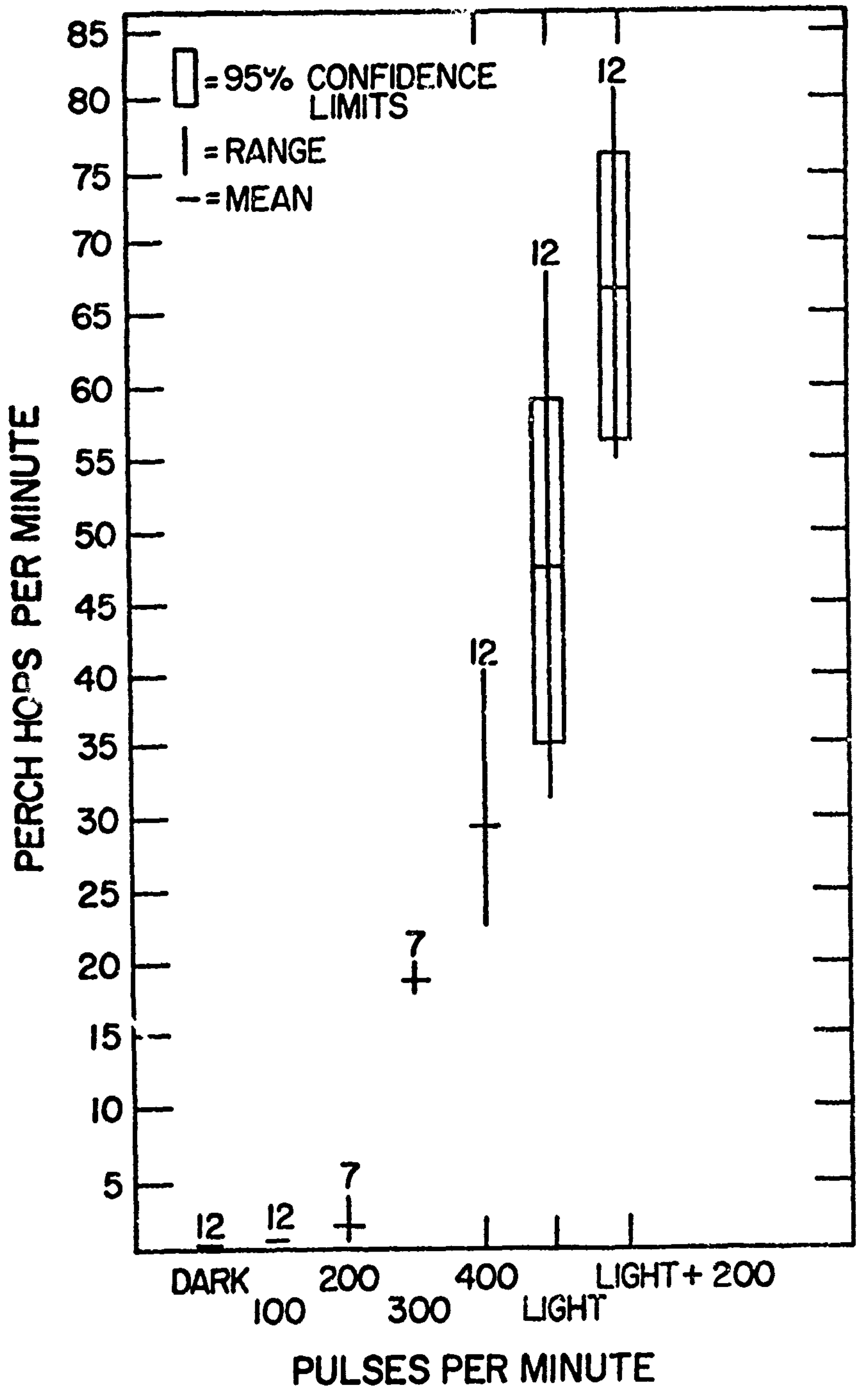


Figure 2. Response of starlings to low intensity light
N = 7-12

does not elicit an avoidance response within 30 to 60 seconds. There is not significant movement in a room simulating night conditions and the bird does not make a distress call. If this same laser beam is aimed at the uninsulated portions of the starling's body (legs, beak and eye), intensities as low as 0.3 to 0.4 W on the birds beak and legs and 0.1 W in the eye will bring out an immediate avoidance response under both simulated day and night conditions.

Since one of the advantages of the laser light over that of the strobe light is greater intensity, we next expanded the laser beam (4-5 in. in diameter) and repeated the previous experiments conducted with the strobe light (on same birds) only this time using laser light of much greater intensity. The bird responded to the various wavelength tested (488-514 nm) in a similar fashion so all the data are pooled in the results. It can be seen from Table II, that the birds reacted to high-intensity laser light (not capable of burning 12 mW/cm^2) in a manner similar to that of a low-intensity strobe light.

As with the strobe light, there was little difference in activity between birds in a darkroom and birds in a darkroom with the laser pulsing at 100 and 200 pulses per minute. Birds in a darkroom exposed to continuous laser light showed no greater activity than those exposed to pulsing light (100/min.) in a darkroom (a mean of 1.7 hops/min versus 1.8 hops/min). There is no significant difference in activity between those starlings exposed to continuous room light (simulated day light) and those exposed to continuous room light plus the laser pulsing at 200 pulses per minute (Table IV).

Table IV also compares the mean responses from the first tests with pulsing light to the mean responses from later tests with pulsing light on the same birds. When one makes this comparison, it becomes obvious that there has been either no significant change or a great reduction in the response. For example, when we first tested the birds using pulsing light (200/min) plus continuous room light, the birds showed a mean activity of 66 perch hops per minute. Under similar conditions, but after repeated testing, the birds showed a mean activity of only 16.7 perch hops per minute, indicating habituation. Another indication of habituation is to determine at what point during the test period (20-30 min) the birds show the greatest response. Table IV indicates that although there is a reduction in the mean activity as computed over the entire test period, the greatest amount of activity occurs in the first few minutes of the test period, (76 perch hops in first 1.5 minutes) again indicating habituation.

As one would expect at higher intensities (2-3 W) the concentrated aimed laser beam, either pulsing (200/min) or continuous, elicited an immediate avoidance response. The high-intensity (2-3 W) expanded (2-3 in.) laser beam caused an initial increase in activity (Table V). Over a 20- to 30- minute test period the initial (first few minutes) rate of perch hopping was 35.6 ± 24 hops per minute, again indicating

TABLE IV

Activity (perch hops/min) responses of starlings to various laser light ranges over a 20- 30-minute test period

Continuous Laser	Total Darkness	Laser 100/min Pulse Rate Dark Room	Laser 200/min + Light	Laser 200/min Dark Room	Cont. Room Light
1.33 (33/2)	0.00	3.0	4.2 (76/1.5)	0.184	13.7
3.6 (101/8)	0.62	5.8 (34/3)	1.0 (24/0.5)	1.5 (47/4)	13.4 (147/7)
1.0 (17/4)	0.33	0.66	2.5 (53/4)	1.2 (16/2)	53
0.89	0.0050	0.2 (4/1)	7.1 (34/0.5)	1.1	41
	0.33	0.1	12.4	2.3 (66/3)	52
	0.35		37.0	3.5 (78/9)	21
	0.00		25.0	2.6 (83/19)	6.6 (74/1.5)
	1.00		45.0	6.7	29
	0.188				
	0.90				
	0.00				
$\overline{X} = 1.7$	$\overline{X} = 0.37 + .33$	$\overline{X} = 1.8 \pm 2.4$	$\overline{X} = 16.7 \pm 16$	$\overline{X} = 2.37 \pm 2$	$\overline{X} = 25.8 \pm 18$
	$\overline{X} = 0.133$*	$\overline{X} = 0.514$*	$\overline{X} = 66.0$*	$\overline{X} = 1.5$*	$\overline{X} = 47.2$*

5.8 (34/3) = 5.8 perch hops per minute over the entire test period, 34 perch hops in the first 3 minutes

*Mean value from previous test (before habituation)

TABLE V

Response of starlings to high-intensity (2-3 W) laser light (expanded and pulsing, 200 pulses/min

Perch hops in first few minutes	Perch hops in last few minutes
103/1.5	13/2
20/5	10/5
20/1.5	0/2
25/1	0/2
40/1	20/1
41/3	0/2
22/2	0/2
44/2	0/2
32/1	3/2
12/2	0/2
33/3	0/2
$\bar{X} = 35.6 \pm 24.5$	$\bar{X} = 4.1$

22/2 = 22 hops in 2 minutes

habituation. The initial rate of activity at high light intensities is not significantly greater than the activity rate of birds on a similar light range of lower intensity. Of course, as the beam is concentrated below 2 inches in diameter at high intensities (3.5 W) there is increased activity.

A combination of high-intensity laser light (2 W, expanded beam) and the starling's distress call produced similar results to that of high-intensity laser light. The majority of the birds tested responded to this combination with increased activity only in the beginning of the 20- to 30-minute test period; again indicating that the birds habituate rapidly.

We were able to deny starlings a territory by using the concentrated aimed laser beam, either pulsing or continuous, at an intensity of from 1 to 3 W. The mean time it took to move the birds was 11.6 ± 11 seconds; 73.4 percent of the time when one bird moved, the others followed. When exposed to the concentrated laser beam the birds moved out of the territory; they then returned a few times (during the first 2-5 minutes of the 20-minute test period) but left immediately when again exposed to the laser. After a few exposures to the concentrated beam (either pulsing or continuous) the bird did not return to the exposed territory in the cage. In fact, the birds would actually fly to midline of the cage and turn around while with the laser off there was random movement between the two territories. The expanded laser beam (0.5 to 4 in. dia.) at an intensity of 2 W had little effect on denying the birds a territory, although in some cases there was greater activity within the exposed territory.

c. Mallard Ducks

Whereas, low-intensity pulsing light brought about an increase in starling activity, it did not have any major effect on the mallard duck. Table VI illustrates the heart rates (beats/min) of mallard ducks after a 4-minute exposure to various light ranges. There was no significant difference in mean heart rate between any of the light ranges. There was a slight increase in the mean heart rate of ducks exposed to low-intensity pulsing light (400/min) and continuous room light. Whenever the light range was changed there was an initial increase in heart rate; this increase lasted in some cases for only a few seconds and seldom for over 4 minutes (Fig. 3). The ducks habituated to the low-intensity light extremely fast.

Noise had more effect on the ducks than pulsing light. A combination of starling distress call and low-intensity pulsing light brought about a 37.5 percent increase in heart rate (from a mean of 150 to a mean of 240). Figure 4 illustrates the instantaneous increase in heart rate with this combination. Again, as with the starling, the ducks did habituate to this combination.

TABLE VI

The heart rate (beats/min) of Mallard ducks after a 4-minute exposure to various light ranges

	Light Range						
Bird No.	Total Darkness	100/min	200/min	300/min	400/min	1000/min	Continuous Light and 400/min
1	240	240	240	240	240	240	300
2	180	144	144	144	156	132	300
3	156	140	140	120	120	120	140
4	170	144	130	144	-	-	-
5	156	160	160	160	156	144	160
6	130	170	130	130	120	130	130
Means	172 ± 37.3	167.3 ± 37.8	157.3 ± 41.9	156.3 ± 43.2	158.4 ± 21.9	153.2 ± 49.0	206 ± 86.7

Mean ± one standard dev.

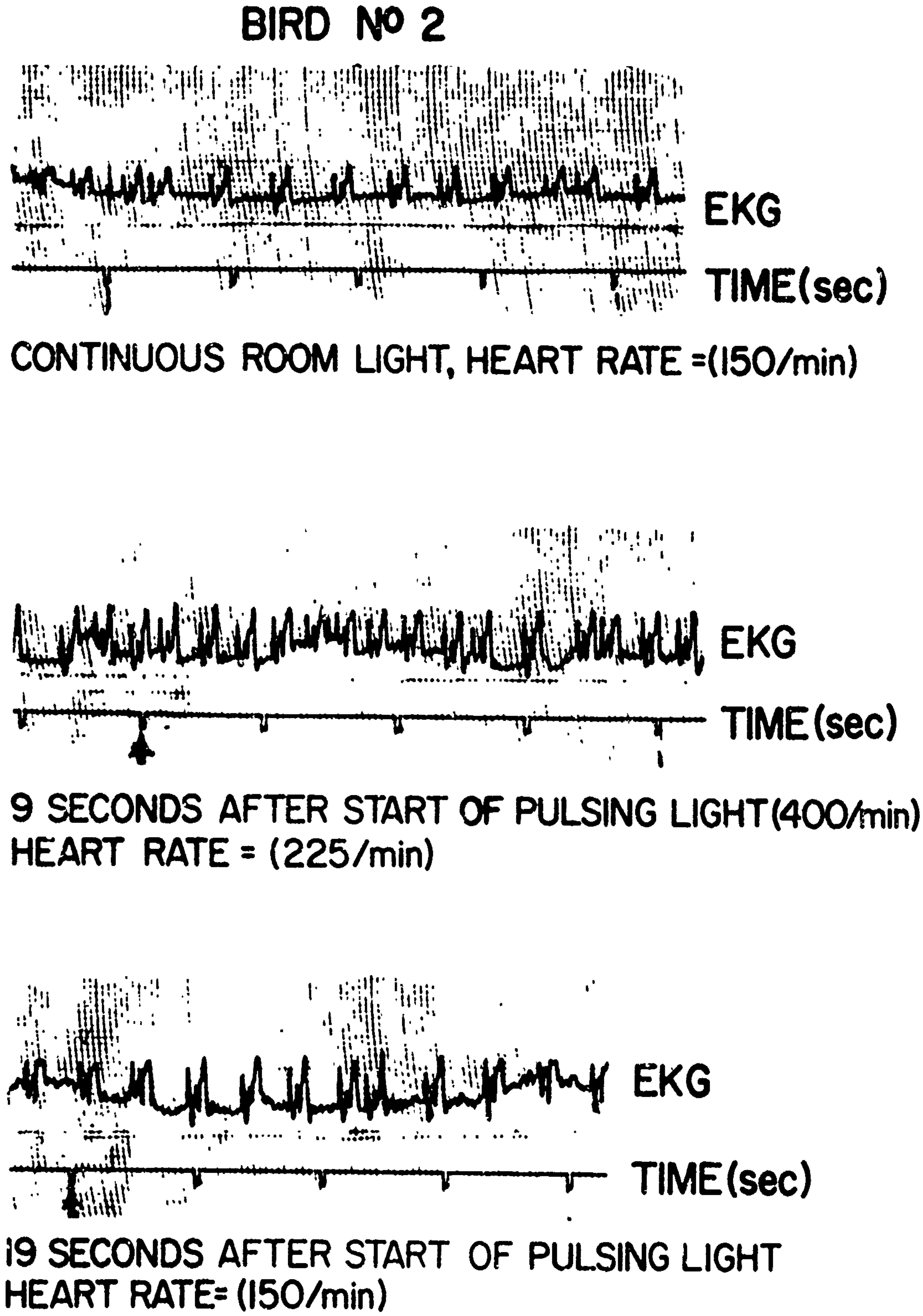


Figure 3. Effects of low intensity pulsing light on Mallard heart rate

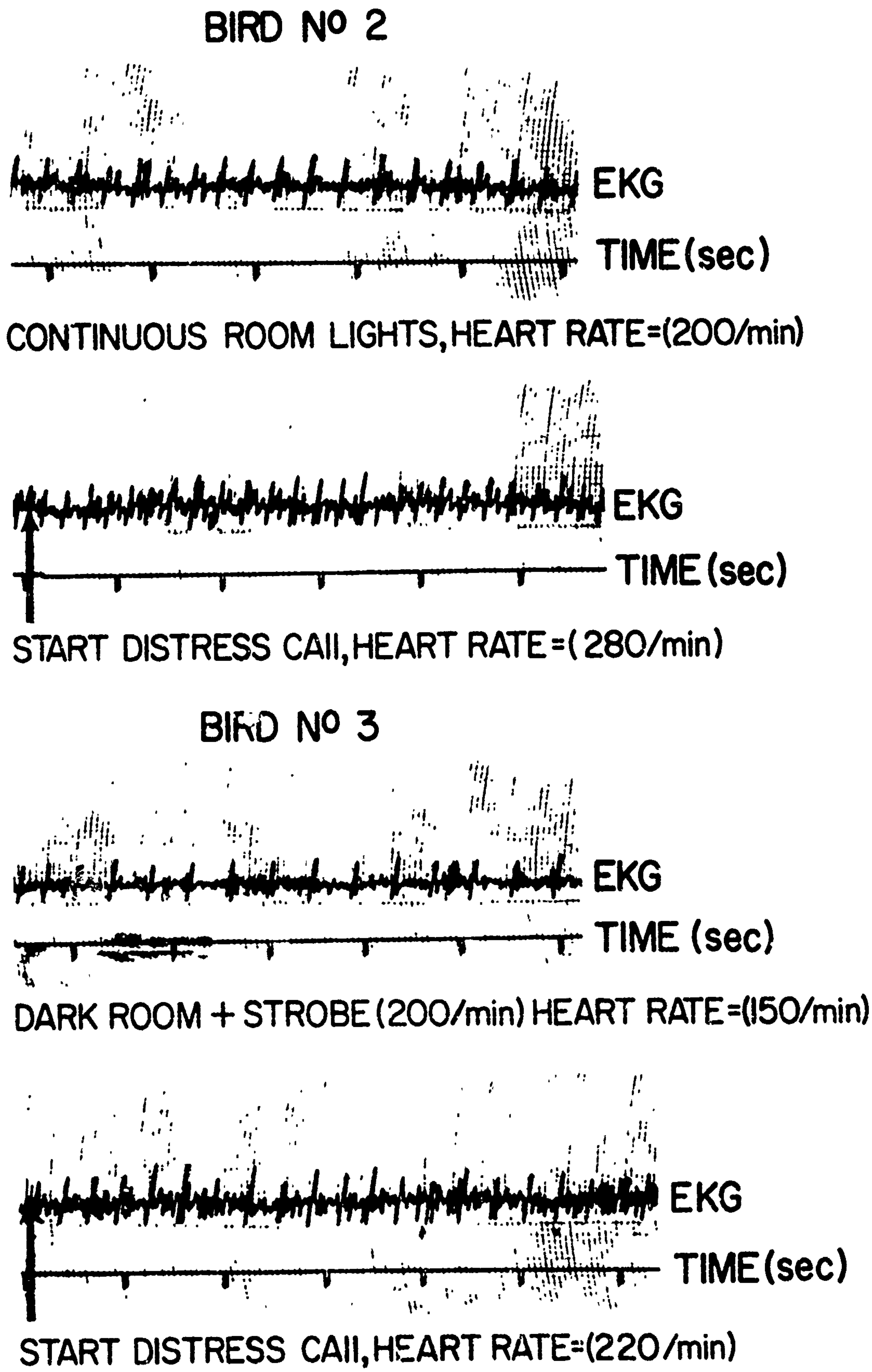


Figure 4. Effect of distress call on Mallard duck heart rate

The mallards were much more sensitive to high-intensity laser light than the starlings. It can be seen (Fig. 5) that there is not a significant ($P > 0.05$) difference in heart rate in birds exposed to either pulsing laser light or continuous laser light at any of the intensities tested. Birds exposed to a concentrated laser beam showed the highest heart rates. Mallards exposed to laser beams (continuous and pulsing) varying in diameter from the concentrated beam (2-5 mm) to 4 inches had significantly ($P < 0.05$) greater mean heart rates than mallards sitting quitely in total darkness and those exposed to laser beams of a diameter greater than 4 inches. It should also be pointed out that the heart rate of mallards exposed to laser beams greater in diameter than 4 inches were not significantly ($P > 0.05$) different from mallards in total darkness.

In addition to heart rate as an indication of excitement, we recorded the percent of the birds avoiding the laser beam and the time it took the bird to avoid the beam. Tables VII and VIII show the percent avoidance and time to avoidance for mallard ducks exposed to various laser light ranges under daytime conditions. It is obvious from these tables that the greater the light intensity on the target the greater the avoidance response. For example, the concentrated laser beam elicited 100-percent avoidance at laser intensities above 0.5 W; whereas, the 2-inch diameter laser beam elicited 100 percent only at laser intensities of 2 W or better. The avoidance responses correlate well with the heart rate data; the best avoidance responses were obtained with laser beams no greater in diameter than 4 inches. Laser beams of 6 inches in diameter did elicit an avoidance response if the intensity was high enough (2 to 3 W).

Under nighttime conditions, our results are similar to those for daytime conditions (Tables IX and X). The greatest amount of avoidance taking place was with laser beams no greater in diameter than 4 inches. The time to avoidance under day and night conditions was extremely fast (less than 60 sec.) for mallards exposed to laser beams of 4 inches in diameter or less (Tables VIII and X).

In many cases, although there was not 100-percent avoidance, the mallards did show a great deal of discomfort and eye irritation as evidenced by head-shaking. Headshaking occurred even with laser beams greater in diameter than 4 inches and occurred almost immediately in birds exposed to laser beams of 4 inches or less in diameter, especially if the intensity setting was above 1 or 2 W.

Unlike the starling, the duck knew the intense light was causing its irritation; in fact, the duck would attack the beam (biting at it). In approximately 25 percent of the tests (concentrated beam 0.5 W or better) the duck elicited a distress call.

The percent avoidance and time to avoidance for groups of three mallards are shown in Tables XI and XII, respectively. The avoidance

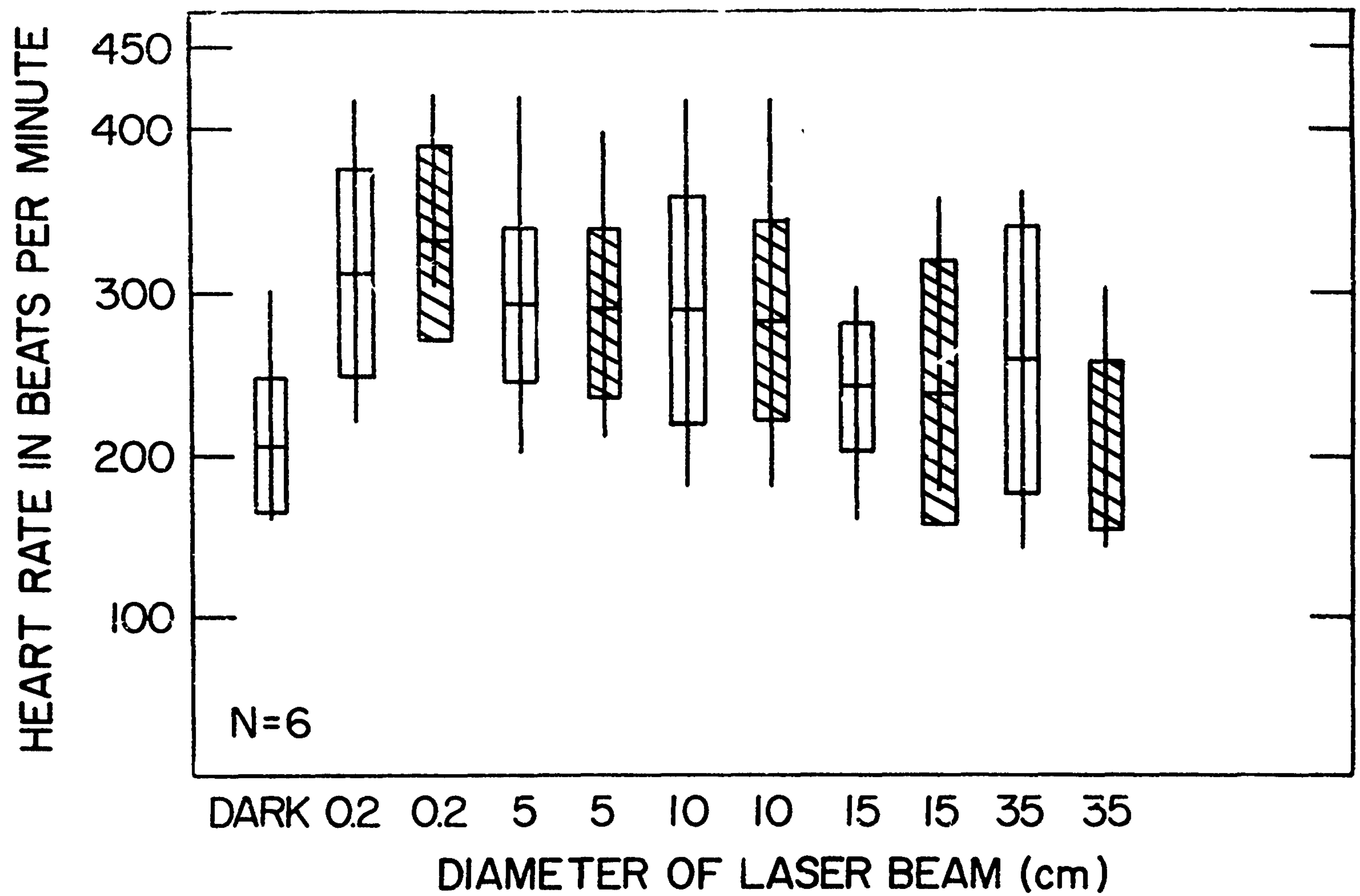


Figure 5. Heart rate of Mallard ducks exposed to 1 W continuous laser (unshaded boxes) and 2 W pulsing (shaded boxes) laser under night conditions. Symbols as in Fig. 2

TABLE VII

Percent of the Mallard ducks avoiding laser light of different intensities under simulated daylight

Diameter of Beam on Target (cm)	Power Setting on Laser in W					
	0.05	0.5	1.0	2.0	3.0	2.0 pulsing
0.2-0.5	14.3	100	100	100	100	100
5.0	33.3	71.5	85.7	100	100	100
10.0	0.0	33.2	42.8	86.7	100	54.4
15.0	0.0	0.0	16.6	66.6	66.6	37.2
35.0	00.0	0.0	0.0	0.0	25	0.0

TABLE VIII

Mean time to avoidance in Mallard ducks exposed to various laser light ranges under simulated daylight (sec.)

Diameter of Beam on Target (cm)	Power Setting on Laser (W)					
	0.05	0.5	1.0	2.0	3.0	2.0 pulsing
0.2-0.5	10.2	6.7 ± 2.7	9.0 ± 4.6	2.8 ± 2.4	15	5.7 ± 2.1
5.0	22	33.3 ± 6.5	24.3 ± 6	16.6 ± 2.6	0.0	15.8 ± 2.0
10.0	--	9.3	9.6 ± 1.9	16.3 ± 4.6	18.8 ± 3.7	9.9 ± 2.1
15.0	--	--	28.4	23.7 ± 7	15.2	28.9 ± 6.3
35.0	--	--	--	--	16.5	--

Means are ± one standard error of the mean.

Only birds eliciting an avoidance response are included in the mean values.

TABLE IX

Percent of the Mallard ducks avoiding laser light of different intensities under simulated night conditions

Diameter of Beam on Target (cm)	Power Setting on Laser (W)					
	0.05	0.5	1.0	2.0	3.0	2.0 pulsing
0.2-0.5	50	100	100	100	100	100
5.0	0.0	40	83.3	83.3	--	75
10.0	0.0	50	33.3	75	--	83.3
15.0	0.0	0.0	14	75	--	50
35.0	0.0	0.0	0.0	0.0	0.0	0.0

-- = birds not tested at this intensity.

TABLE X

Mean time to avoidance in Mallard ducks exposed to various laser light ranges under simulated night conditions (sec.)

Diameter of Bear on Target (cm)	Power Setting on Laser (W)					
	0.05	0.5	1.0	2.0	3.0	2.0 pulsing
0.2-0.5	34	3.7 ± 3.7	5.0 ± 5	0.0	0.0	0.0
5.0	---	18.7	21.8 ± 3.5	23.9 ± 5.7	×-	15.7 ± 2.7
10.0	--	13.0	45.0	26.3 ± 2.8	×-	17.0 ± 5.1
15.0	--	--	45.0	50.6 ± 5.2	×-	33.5 ± 5.4
35.0	--	--	--	--	--	--

Means are ± one standard error of the mean.

Only birds eliciting an avoidance response are included in the means.

-- = no response

×- = not tested

TABLE XI

Percent avoidance of groups (3/group) of Mallard ducks to various laser light ranges

Diameter of Beam (cm)	Power Setting on Laser (W)					
	0.05	0.5	1.0	2.0	3.0	2.0 pulsing
0.2-0.5	42.8	87.5	100	100	100	93.8
5.0	0	16.6	57	71.5	75	55.5
10.0	0	0	50	50	75	50
15.0	0	0	0	0	33.3	0

TABLE XII

Mean time to avoidance in groups of Mallard ducks exposed to various laser light ranges (daytime conditions)

Diameter of Beam (cm)	Power Setting on Laser (W)					
	0.05	0.5	1.0	2.0	3.0	2.0 pulsing
0.2-0.5	11.4	13.0	6.8	5.4	3.5	8.0
5.0	--	8.6	4.1	10.3	9.3	9.3
10.0	--	--	33.7	21.5	27.0	20.4
15.0	--	--	--	--	43.7	--

responses in groups of ducks were similar to those of the individual ducks. Again the best avoidance response was elicited by a concentrated laser beam of 0.5 W or better intensity, while a laser beam greater than 4 inches in diameter (up to 3 W intensity) had little effect.

Though the avoidance responses were similar between the groups and individual ducks, there was an increase (up to 50 %) in the amount of distress calling in groups. Even at intensities that did not elicit a definite avoidance response there was some distress calling plus a continuous nervous chatter among the ducks in the group.

d. Gulls

The response of individual gulls to intense laser light was similar to that of the starlings in that only the concentrated laser beam elicited a significant avoidance response (Tables XIII and XIV). At beam diameters above 1 cm, the gulls failed to elicit an avoidance response more than 37.2 percent of the time. Though the gull failed to avoid the expanded (2 cm - 15 cm) laser beam, they did show some irritation (head-shaking, eye-rubbing). Like the ducks, the gulls identified the source of irritation and would attack the laser beam on many occasions.

The response of groups of three gulls to intense laser light was similar to that of the individual gulls. The concentrated beam brought about severe head-shaking and eye-rubbing, with the birds attacking the beam. The beam elicited a distress call in 25 percent of the tests, there did not seem to be a group response. This lack of a group response can be explained because the birds established a peck order among themselves which seemed to elicit a greater avoidance response than the concentrated laser beam. Low-intensity pulsing light (100, 200, 300, 400, 600, 1000, 2000, 4000, and 25,000 pulses/min) from the strobe elicited only slight displacement behavior, as pecking at the cage and head-shaking. The pulse rates that elicited the greatest amount of displacement behavior were 400 and 600 pulses per minute.

TABLE XIII

Percent of the gulls avoiding laser light of different intensities

Diameter of Beam on Target (cm)	Power Setting on Laser (W) 0.05	0.5	1.0	2.0	3.0	2.0 pulsing
0.2-0.5	8.3	69.3	91.5	85	71.3	89.5
1.0	0	12.5	25	55.6	37.5	16.7
2.0	0.0	10	37.2	33	17.7	0.0
5.0	0.0	0.0	14.3	8.3	0.0	6.2
10.0	0.0	0.0	0.0	0.0	0.0	0.0
15.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE XIV

Mean time to avoidance in gulls exposed to various laser light ranges (sec.)

Diameter of Beam on Target (cm)	Power Setting of Laser (W)					
	0.05	0.5	1.0	2.0	3.0	2.0 pulsing
0.2-0.5	41	7.1	11.8	8.3	2.2	23.3
1.0	--	4	0.0	7.3	0.0	0.0
2.0	--	0.0	11	15	0.0	--
5.0	--	--	9.2	38.[illegible]	--	7
10.0	--	--	--	--	--	--
15.0	--	--	--	--	--	--

Only birds eliciting an avoidance response are included in the means.

SECTION IV

DISCUSSION

It has been known for centuries that light (photoperiod) is possibly the major environmental stimuli affecting bird behavior and physiology. The length of the light period stimulates the breeding cycle, migration, fat deposition, and molt in most species of birds. Therefore, it is only natural that one would think of using light as a means of bird control. In fact, light has already been used as a bird control; floodlight traps have been used to trap blackbirds;[9] Meanley states that 2000-W search lights have been used to alleviate depredation by ducks in rice fields.[10]

Pulsing light is already used on aircraft, aircraft hangers and high towers as a means of detouring the birds.

With some positive results already obtained with light as a bird control, the next step is to see if a better light source (the laser) might not have a greater effect. The laser is basically an intense and coherent light with extreme directivity and, thus, might have greater influence on a bird's behavioral and physiological responses.

Practical lasers which cover a wide range of the spectrum are now available, any one of which could be tried in bird control experiments. Before selecting a laser it is necessary to understand something about bird vision. All the available evidence tends to support the belief that the visual acuity of birds is of the same order as that of man, but that the rate of assimilation of detail in the visual field is much higher in birds.[11] Also a bird with a single glance lasting perhaps a second takes in a picture which a man could accumulate only by laboriously scanning the whole field piece by piece with the most accurate portions of the retina. The fact that the visual information is taken in by birds at a high rate and simultaneously over a greater part of the visual field has been substantiated by studies of bird navigation,[12] for the only theory of navigation consistent with the evidence implies that birds can assess not only the elevation of the sun but also its rate of change of elevation and its azimuth with high accuracy.

Anyone who has ever watched birds doubts that their reception of color is as good as that of man. The studies of Watson,[13] Lashley,[14] and Hamilton and Coleman[15] have shown that the curve relating the least perceptible change of wavelength to wavelength has exactly the same form for the pigeon as for man, suggesting that the fundamental mechanisms for discriminating pure colors is the same for both. There is no satisfactory evidence that birds make use of extra-spectral frequencies at either end of the visible spectrum. Matthews and Matthews[16] showed that the dioptric system is quite opaque to infrared light.

Spectrophotometric analysis of visual pigment extracts prepared from various species of bird retinas have led to some valuable information. Crescitelli[17,18] found the great horned owl, screech owl, gull, and pelican to possess pigments with maximum absorption at wavelengths of 502, 503, 501, and 502 nm, respectively. Bridges,[19] found the maximum absorption at 502 nm for the duck. Recently, Sillman[20] extracted, analyzed, and characterized the visual pigments of 20 species of birds, representing 8 orders and 11 families. He found that each species examined yielded at least one visual pigment. In every case the major pigment (and the only pigment in 14 species) exhibited a maximum absorption within the spectral range of 500 to 506 nm. In five species of passerines, a second photopigment was detected which ranged in maximum absorbance from 480 to 490 nm, and which constituted from 5 to 10 percent of the total pigment content. It is highly probable that the major pigment isolated in these studies were scotopic or rhodopsin. In fact, in the work cited so far there has been no evidence for the presence of any cone pigments. Three species of birds have been reported to possess other pigments in addition to the rhodopsin.[21,22,23] This pigment (iodopsin) has a maximum absorbance ranging from 544 nm in the pigeon to 562 nm in the chicken and turkey. The important factor coming out of these studies is that the dominant photopigment displays a marked constancy in the spectral location of 500-506 nm. This being the spectral wavelength that birds are most sensitive to suggests that one would want to use a laser which includes this range. The argon laser emits light over a spectral range of from 454 to 514 nm and, thus, would seem to be that to which birds are most sensitive. It should be pointed out that because few cone pigments have been found does not eliminate the possibility of their presence and it is possible that other wavelengths might be as effective or more effective in bird control.

1. STARLINGS

It is only natural that the starling, being a diurnal bird, will be more active during the daylight hours. This explains somewhat why there was an increase in activity with an increasing pulse rate (Fig. 2) under simulated night conditions--the shorter the dark period the greater the activity. Of greater interest is that there was significantly greater activity under simulated daytime conditions plus pulsing light than under simulated daylight alone. This indicates that pulsing light is annoying to the starling causing an increase in activity. That the starlings habituate to pulsing light was shown by the decrease in activity when exposed again to pulsing laser light; overall response was much less under daytime conditions plus the pulsing laser. Also the activity decreased during the test period (Table IV), again indicating habituation.

The response of the starling to high-intensity laser light of different wavelengths (488 and 514 nm) was similar. One would expect this response since the peak sensitivity of the bird was between 500-506 nm

(Fig. 6); thus, the starlings were equally sensitive to 488 and 514 nm. The remainder of the experiments were carried out using the all-wavelength mirror (454-514 nm).

As far as a bird strike with a flying airplane is concerned, it is more than likely that the initial response is important. This initial avoidance response would cause the bird to avoid the oncoming plane if the light source could be seen far enough in advance, thus giving the bird time to avoid a high-speed plane. In the case of the starling, pulsing light is much better than continuous light as a control, mainly because a continuous light source at night could act as an attractant for starlings,[7] where pulsing light is annoying. Remembering that the intense (1-3 W) expanded 4 inch laser beam gave results similar to the low-intensity strobe light, what then is the advantage of the laser? Of course the answer to this question is effective distance. The laser beam, having less divergence, has a greater range which, in turn, gives the bird more time to avoid the plane.

Although it was thought that the starlings would not habituate to intense laser light because it is irritating to the eye, the only laser beam that the starlings did not habituate to in the laboratory was the concentrated beam of at least 0.5-W intensity (irritating). This light range would deny starlings territory. Birds exposed to the beam a few times no longer returned to the area and the birds could be moved at will. Of course this is a highly focused light beam and must be accurately aimed since it can cause eye damage to man. The feasibility of using the concentrated laser beam as a bird control is discussed in a later section.

One can only speculate as to why the starlings and gulls (diurnal birds in general) are not sensitive to extremely intense laser light (expanded beam) capable of doing considerable damage to the mammalian eye. The birds should be extremely sensitive to the argon laser light since their rhodopsin has its peak sensitivity (Fig. 6) between 502-506 nm and the laser has it's greatest power in this range also (Table I). Why then no headshaking or avoidance when exposed to continuous laser light (expanded beam)?

It is known that some birds "sun orient",[24] i.e., they look directly at the sun in order to get some idea of the azimuth. It is also known that birds fly at very high altitudes (23,000 ft.) where solar radiation is extremely intense. One need only look from an airplane window into the sun when flying it at 23,000 feet to determine just how intense it is. Yet these birds fly with their eyes open and possibly, looking right at the sun. Two hypotheses can be set forth to explain the ability of birds to withstand intense light. The first deals with the pecten, a pigmented conical, highly vascularized body. It arises near the attachment of the optic nerve and juts out in the vitreous humor toward the lens. It is an elaborate structure of thin folds richly supplied with small blood vessels (not capillaries). According

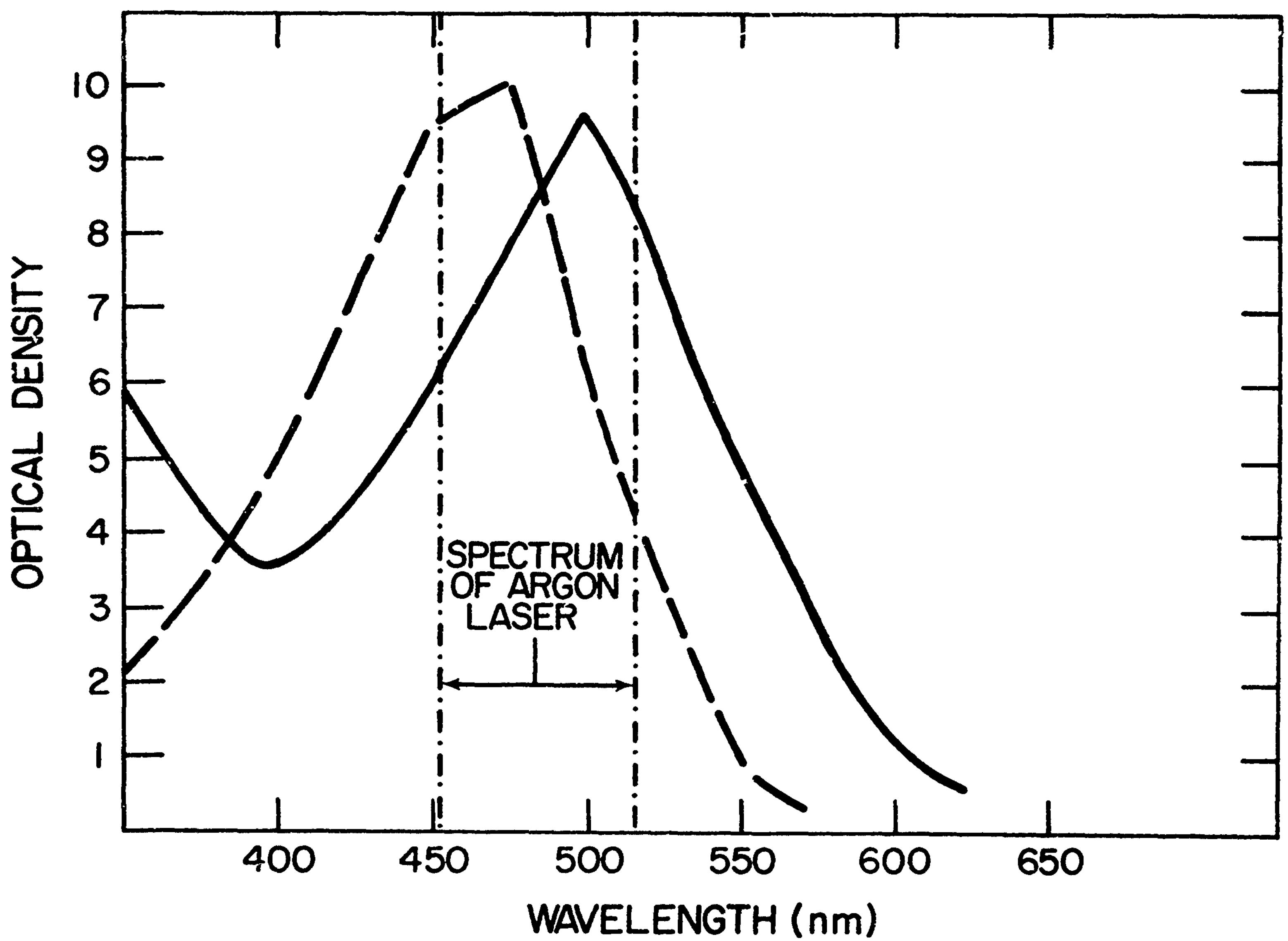


Figure 6. Absorbance spectra of oil droplets (--) and visual pigment extract (-), adapted from Sillman (1969)

to Walls,[25] over 30 theories have been proposed to explain the function of the pecten, one of which is light absorption. The position of the pecten is such that it shades the fovea, thus decreasing the effect of intense light. Another feature of the pecten, its vascularity, would also explain how the heat of the laser beam is dispersed without burning the retina; for example, 4 watts for 30 seconds is equal to 120 joules or 28.5 calories. When concentrated by the lens of the eye this would be a tremendous heat load for the retina if it were not for some means of dispersing it.

The second hypothesis deals with the colored oil droplets found in the eyes of birds and reptiles. It is usually thought that these oil droplets enhance color vision by acting as filters. When one compares the absorption spectrum of the rhodopsin with the absorption spectrum of the oil droplets (Fig. 6) he will see that they overlap somewhat, especially between the wavelengths of 450 and 510 nm where birds have their greatest sensitivity.[20] As Sillman points out, the biological significance of the oil droplets still remains to be determined. Both reptiles and birds that are exposed to intense solar radiation (reptiles in deserts, birds at high altitudes) possess oil droplets. It has long been thought that the colored oil droplets enhance color vision; Ducker and Tiemann[26] have shown that oil droplets in reptiles have little to do with color vision. It is possible that these colored oil droplets act as filters for the intense light. The mechanism by which they could accomplish this is unknown, and further research into bird vision is necessary to determine if either the pecten or oil droplets are responsible for the diurnal birds' ability to look at intense light without any gross effects.

2. MALLARD DUCKS

As with the starlings, the mallards habituated to low-intensity pulsing light extremely fast, there being no significant different in heart rate after four minutes in any of the low-intensity light ranges (Table VI). Although there was little response to low-intensity light, the mallards were much more sensitive to high-intensity laser light than the starlings. This is understandable if one knows something about the behavior of the mallard duck. According to Winner[27] the mallard duck moves to and from its feeding grounds during periods of very low light intensity (less than 0.1 ft-c). Also like many other waterfowl they are known to migrate at night. This would indicate that they have relatively good night vision. Indeed, they could see the investigator in a dimly illuminated room where the starlings could not see the investigator at all. In fact, the starlings would not move and could be picked up by hand in a dark room. The nocturnal feeding behavior of the mallard has already allowed rice farmers to use light as a control (illuminate rice fields and ducks do not feed). As Sillman[20] pointed out, nocturnal birds have a greater amount of rhodopsin (rod pigment) and, thus, would be expected to have greater sensitivity to light especially over the wavelengths emitted by the argon laser, since it is here that bird rhodopsin has its peak sensitivity.

To bring about an avoidance response in the mallard of at least 50 percent, the intensity of laser light hitting the bird had to be at least 0.01-0.025 W/cm^2. Using the present laser system, the beam could only be expanded six inches and still give high enough intensities. Not only is it important that the bird avoid the laser beam but the time it takes the bird to avoid the light beam is equally important. In this study, for a response to be considered as avoidance response it had to occur within 60 seconds. As the flight speed of aircraft increases, response time will become even more important. For example, a plane flying 600 miles per hour will travel 10 miles in 60 seconds indicating that if the bird is 10 miles away, it only has 60 seconds to avoid the plane. This points out another problem which we will discuss later, that is, the effective distance over which a laser beam can elicit an avoidance response. If the bird is only 1 mile away and the plane is traveling at 600 miles per hour, then the bird has to respond in six seconds or collide with the aircraft. Again, as with the starling, the concentrated laser beam elicited the greatest and fastest avoidance response; avoidance is almost immediate.

The duck identified the laser beam as the source of irritation and in some cases would bite at it, whereas the starling did not seem to recognize the source of irritation. This explains somewhat why the the ducks elicited a distress call when exposed to high-intensity light and the starling did not. If the starling realized what the distress was (grabbing the bird) it too elicited a distress call. Equally important to an individual bird response is the response of a group of birds to the coherent laser light, since the beam cannot possibly hit every bird in the group. Although our groups were small (3 birds/group) there was a group avoidance response. The individuals not affected by the laser beam followed birds trying to avoid the beam.

3. GULLS

The gulls like the starlings, are diurnal birds, active during the daylight hours and quiet during the dark. Thus, one would expect them to have some mechanism for filtering out intense solar radiation. Although the expanded laser beam seemed to irritate the gulls (head-shaking, eye-rubbing) more than it did the starlings, the only laser beam that elicited an avoidance response was the concentrated beam of at least 0.5 W intensity. The lack of a demonstratable group avoidance (found in starlings and ducks) response in the gulls might well depend on the size of the test cage (60 ft^3). The gulls had established a pecking order and were afraid to get too close to each other; thus, if the dominant bird moved to another area, the subordinate bird did not follow. Since the gulls associated the distress with the intense light (bite at beam), they did utter a distress call and we know that under natural conditions a gull distress call will cause the birds to leave the area at least temporarily.

4. PROBLEMS FACED BY AIRCRAFT

The problem of air strikes is largely a function of airport location and construction. Runways built on or near ideal bird habitats bring birds and aircraft into conflict. The low, flat areas ideal for airports are frequently associated with water or marshland vegetation, which may be the breeding or roosting sites of large water birds or flocking, smaller, perching birds. The general construction of airports and large open spaces with extensive areas of short-cut grass provide a large amount of plant and invertebrate material to attract birds. Under conditions such as described, the majority of bird strikes would occur during landing and takeoff. Records show that about 95 percent of the bird strikes occur below 6000 feet and 60 percent below 2000 feet, at least for commerical airlines. For military aircraft, approximately 95 percent of the bird strikes happen below 2000 feet and about 70 percent below 500 feet. Thus, we are faced with two basic problems in controlling birds: (1) to keep the birds off the runway to minimize the probability that aircraft approaching and landing and taking off and climbing to altitude encounter birds and (2), to keep birds that are flying at low altitudes out of the path of low-flying planes, especially high-speed military aircraft. Seven F-104 jets were lost in Canada because of bird strikes at low-altitude, high-speed flight.

Several factors enter into the design of a bird control under these conditions:

1. species specificity,
2. pulsing or continuous light,
3. effective distance and effective power,
4. habituation, and
5. speed of the aircraft (avoidance time).

Now let's take each factor separately and apply it to the laser as a means of control. Many diverse ways (noise makers, distress calls, falcons) of scaring birds have from time to time been tried to control birds around airports, but have generally been found wanting. They have been inadequate mainly because they are either species-specific or the birds habituate to them. The best control would be one that is nonspecies specific and that the birds would not habituate to. The laser system used in these tests fulfill both these requirements as long as the beam is irritating (concentrated). None of the species tested (repeatedly) failed to avoid a concentrated laser beam of at least 0.5 W, indicating it was nonspecies-specific and they did not habituate to it.

Once expanded (light intense but not capable of burning) the continuous laser beam was no longer species-specific under the laboratory conditions, in fact starlings, and gulls to a lesser extent, could look directly into the beam without showing avoidance response. Pulsing laser light (expanded beam) did increase the initial activity of the starlings. Mallards were also sensitive to laser beams (pulsing or continuous) expanded up to 6 inches in diameter and showed little habituation to these beams at high intensities. It becomes clear that equally as important as laser intensity to species specificity is whether the laser is pulsing or continuous. Though a diurnal bird would not usually fly at night, if scared by a landing or leaving aircraft flying over their roost at night, they might fly toward a continuous light source, whereas a pulsing light (100-200 pulses/min) would seem to elicit an avoidance response. The nocturnal flying birds would most likely be repelled by either pulsing or continuous laser light.

The effective power of the laser at different beam diameters was calculated (Table II). It is obvious that the nonspecificity of the concentrated laser beam is due to the burning and not the light itself (especially since this highly aimed beam affects the bird even when aimed at the leg). For example, the time it took to move a mallard duck with the concentrated beam at 0.5 W was approximately 7 seconds. At this intensity the duck was hit with light at an intensity of 14.6 W/cm^2 (Table II); in 1 second this is equivalent to 14.6 J/cm^2; in 7 seconds (mean avoidance time) it is equivalent to 102.2 J/cm^2 or 24.7 cal/cm^2. This is enough heat to raise 1 gram of water to 24.7°C. This was the minimum tested power capable of elicitin an avoidance response in starlings and gulls. Schaefer[9] found that 6 J/cm^2 is required to ignite flight feathers. Powers as low as 0.3 W/cm^2 were capable of eliciting an avoidance response in duck. It should be pointed out that the concentrated laser beam would elicit an avoidance response no matter where it hit the bird, although the response was faster if the beam was aimed at the unfeathered portions (eye and bill).

The large size of airports (runways) and the high flight speeds of modern aircraft indicates that the effective distance of any control system will be extremely important in its use. Knowing the diameter of the laser beam needed to elicit a response at various power settings (W), one can calculate the effective distance of the laser.

The dispersion of the laser beam as it travels from the laser only, or from a laser/telescope combination where the focal point of one lens in the telescope exactly overlaps the focal point of the other lens is expressed by the equations

$$\theta = 1.22 \frac{\lambda}{D}$$

$$R(2 \times \theta) = d$$

$$d + D = \text{dispersion of beam at distance } R$$

where

λ is the wavelength (cm),

D is the diameter of the beam at the output of the laser or telescope,

R is the distance to target,

θ is the angle of dispersion, and

d is the dispersion at distance R.

Table XV illustrates the diameter of the beam at various distances when the laser is used by itself and when the telescope used in this study (eye piece 9 mm focal length, objective lens 172 mm focal length) is in phase (telescope lenses are 181 mm apart). If we consider a diameter of from 0.2 to 0.5 cm (0.5 W or better) as the only laser beam which is not species-specific, it becomes obvious that the laser by itself will not be very efficient since its effective distance is extremely short (in 5 m the beam will be 0.55 cm in diameter). In 1 km the beam will be 80.15 cm in diameter (using only the laser). Using the in-phase telescope the beam can never be smaller in diameter than 3.5 cm (the diameter of the beam as it leaves the objectives lens). What is important is that now (using the telescope) at 1 km the beam is only 6.9 cm in diameter, whereas it was 80.15 cm in diameter using only the laser; thus, the telescope has increased the effective distance of the laser. Of course the telescope is adjustable, i.e., we can vary the distance between the lenses. As we increase the distance (above 181 mm) the beam will converge; as we decrease the distance (below 181 mm) the beam diverge much more than previously discussed. Thus, by choosing the proper telescope and by varying the distances between the lens one can obtain a concentrated laser beam at a much greater distance (Table XVI). It should be pointed out here that we have been discussing only those laser beams that were capable of bringing about 50 percent or better avoidance in the laboratory. This does not mean that a beam 1 m in diameter in the wild would not cause a flying bird to avoid the plane. Soloman[28] has reported that radar has shown night-flying geese to avoid a landing plane with its landing lights on. It is obvious that those birds were not irritated by intense light, they just saw the plane in time to avoid it. Under these conditions the laser with its greater effective distance would give the birds more time to avoid the aircraft, avoidance time being extremely important in high-speed, low-altitude flight.

We are concerned with a light source (laser beam) intense enough to bring about an avoidance response for control of birds on the runway, and we would thus need additional optics capable of delivering an intensely concentrated beam at a distance of at least 1000 meters.

TABLE XV

Beam expansion with distance in the argon laser, Model 165-03, and this same laser plus additional optics (telescope described in present experiments)

Distance (m)	Diameter of beam, laser (cm)	Diameter of beam, laser + telescope (cm)
1	0.23	3.503
5	0.55	3.517
10	0.95	3.53
100	8.15	3.84
500	40.15	5.20
1000	80.15	6.90
2000	160.15	10.3
3000	240.15	13.7

In the telescope the focal point of the objective lens exactly overlaps the focal point of the eyepiece lens.

TABLE XVI

Increased distance (greater than 181 mm) between objective and eyepiece lenses necessary to give a laser beam of 0.2-cm diameter on the target at various distances

Distance (m)	Increased Distance Between Lenses (mm)	Diameter of Beam (cm)
1.0	24.0*	0.2
10.0	2.8	0.2
100.0	0.3	0.2
1000.0	0.03	0.2
2000.0	0.014	0.2
3000.0	0.010	0.2

*Not obtainable with the present system (limited adjustment in the telescope).

5. PROBLEMS IN USE OF LASER AS A CONTROL

When considering the problems (hazards) of using intense light as a bird control one must think in terms of the two control situations: (1) control of resident birds at the airport, and (2) control of birds encountered in flight. If the control in the airport situation is to be nonspecies specific, then either a concentrated laser beam will be used or an expanded beam of much greater power since it takes at least 6 J/cm^2 to be irritating to the bird. This presents a human hazard since the acceptable safety limit to the human eye for irradiation from the argon laser is 20 mW for 1 ms.[29] In our experiments it took at least 500 mW to get an avoidance response from starlings and gulls; this is well above the safety limit. One possible way of alleviating the danger to the human eye would be to use a laser emitting in the infrared wavelengths, to which human eyes are not as sensitive. Another problem is that the more concentrated the beam, the more accurately it has to be aimed, indicating either that it has to be manned continually or radar aimed.

Though some birds might respond to a lower intensity beam (not eye irritating), it is possible that on cold days the heat energy contained in the laser beam would actually attract the birds instead of repelling them. Lustick[30,31,32] has shown that birds, when at ambient temperature below their lower critical temperature, will use incoming solar radiation between the wavelengths of 400 and 1400 nm to decrease the energy cost of maintaining a constant body temperature, and, thus, bask under artificial sunlight at low ambient temperatures.

With any light source, especially around airports, (usually built in low-lying marsh areas) fog is going to disrupt the light efficiency as a control method by cutting down on its intensity and effective distance.

These same problems will occur in flight, except that in flight the concentrated beam becomes more dangerous since it would be extremely difficult to aim. For example, a landing plane using a long-range laser beam might focus on another plane, or something or someone on the ground. Also the system described in this study is water-cooled, requiring 2.2 gallons of water per minute, thus, making it difficult to mount on an airplane. However, there are argon lasers that are air cooled also capable of putting out high-energy pulses. These would function as long as continuous laser energy is not needed.

6. SUGGESTED METHOD OF USE AND FEASIBILITY OF THE ARGON LASER AS A BIRD CONTROL

Again we have to consider the two control situations: (1) birds inhabiting (nesting, feeding) the runways and immediately adjacent areas, and (2) birds or bird flocks encounted in level flight. As mentioned previously, the concentrated laser beam is nonspecies specific and would seem to be the best means of dispersing birds that are on the runways. In fact, resident birds exposed to an irritating laser beam a few times would soon learn to avoid the area. A system similar to that used with biosonics[33] might be set up with lasers. Lasers equipped with zoom telescopes positioned so that they could scan the entire field 4 inches above the ground could be controlled from a central point. Birds land on a particular part of the field and the observer turns on the laser scanning that portion of the field. To increase safety one would want a 6 inch high black metal shield around the perimeter of the field to trap the beam. An infrared laser would work equally as well as the argon device with less hazard to the human eye. The number of lasers required would depend on the type of telescope used (effective distance). An alternative to this method would be a mobile unit with the laser mounted in it. This method would be less expensive but would require a person to aim it accurately. This concentrated beam would be the only feasible way of denying all birds the airfield as a habitat.

Another method of keeping birds off the airfield that needs further research is a combination laser and distress call. Biosonics (amplifying the taped distress call to birds) has been somewhat successful but the birds soon habituate to it, or return to the area after the sound stops. The reason for this is that there is no actual distress. By combining the concentrated laser beam with the distress call it is possible that the bird after a few exposures will no longer habituate to the distress call. Here we are using the laser to reinforce the distress call.

In flight we are faced with a different problem. In this instance, I do not think a concentrated (irritation) laser beam could be used, though Shaefer[8] has suggested using lasers to burn the flight feathers off of the birds in the path of airplanes. What should be used is an expanded laser beam of low intensity with the advantage of laser light over regular landing lights being a greater effective distance, thus giving birds a longer time to avoid the plane. For example, a laser and telescope combination that emitted a beam 6 inches in diameter (2 W) would disperse to only 14 inches in diameter in 10 kilometers. The power 1 cm in front of the laser would be 11 mW/cm^2, and in 10 kilometers the power would be 2 mW/cm^2. Also it should be a laser pulsing approximately 100 to 200 per minute, thus diurnal birds at night would not be attracted toward the aircraft and at the powers just described the laser would not be irritating to the human eye. Here the use of radar to forewarn the pilot that he is apt to fly into a flock of birds would increase the efficiency of this method. If no other planes were in the area and the pilot were flying in level flight, a more intense, expanded beam could be used and the bird would have even greater time to avoid the plane.

Research required prior to using the methods described:

1. Determine the effects that weather (rain, ambient temperature, fog) might have on the efficiency of the laser as a bird control.

2. Determine the effects of the intense laser light on other diurnal and nocturnal species to ascertain if the responses described here are consistent; i.e., diurnal birds are not as sensitive to intense light as nocturnal birds.

3. Test synergistic effects of the concentrated laser plus the distress call (biosonics) on the birds response. Basically, the irritating laser would be used to reinforce the distress call, thus cutting down on habituation.

4. Try other wavelengths; the fact that birds have their greatest visual sensitivity at wavelengths between 500 and 506 nm does not rule out the possibility that there are cone pigments more sensitive to other wavelengths in theyyellow or red.

5. Trial test under airport conditions.

6. A side light to bird control but an extremely interesting one would be further research into the filtering mechanism (pecten or oil droplets) within the eye of bird.

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